Probing chiral dynamics by charged-pion correlations[*]

Jørgen Randrup

Chiral symmetry is expected to become nearly restored in the hot zone produced by high-energy nuclear collisions. To facilitate the experimental exploration of this novel phase of matter, we have sought to indentify signals based exclusively on charged pions, which would lend themselves to experimental detection relatively easily.

The initial violent collision of the two nuclei is followed by a rapid expansion, which at first proceeds in the longitudinal direction and then gradually builds up transversly as well. The chiral order parameter $\langle q\bar{q}\rangle$ then reverts from its initial small value to its large vacuum value f_π in a non-equilibrium fashion and the effective pion mass μ has a correspondingly intricate evolution, displaying an overall decay towards the free mass overlaid by the effect of the oscillations exhibited by the relaxing order parameter.

This behavior may lead to parametric amplification of the pionic field with an attendant production of additional pions whose characteristics are sensitive to the chiral relaxation dynamics and which may therefore provide information on the chiral phase transition.

Earlier simulations within the semi-classical linear σ model [1] have already identified a number of candidate observables, including a marked enhancement below $p_T \approx 200$ MeV/c and an associated anomalous increase in the fluctuation of the soft-pion multiplicity. The present study discusses a novel observable, the approximately back-to-back correlation between charge-conjugate soft pions, which is based on the key feature that the basic production mechanism creates neither momentum nor charge.

The effect is easiest to understand in a uniform medium, where the time-dependent quasiparticle annihilation operator is given by

$$\hat{A}^\pm_{\mathbf{k}}(t) = U_k(t)\hat{A}^\pm_{\mathbf{k}} + V_k(t)^*(\hat{A}^\mp_{-\mathbf{k}})^\dagger .$$

The Bogoliubov coefficients $U_k(t)$ and $V_k(t)$ are determined by the pion field equation and thus depend on the specific form of the pion effective mass, $\mu(t)$.

The associated the correlation between oppositely charged pions is then

$$\sigma^{+-}_{\mathbf{k'k}}(t) = |U_k(t)|^2|V_k(t)|^2(N_k+\bar{N}_k)^2\,\delta_{\mathbf{k'},-\mathbf{k}} ,$$

exhibiting the back-to-back correlation.

The strict correlation in the uniform medium is eroded only moderately in more realistic scenarios where a surface is present, as illustrated in the figure (which uses the quantum-field treatment developed in [2] for a space and time dependent effective mass $\mu(x,t)$ emulating the results obtained in [1] for a sample of Bjorken rods with the initial temperature of $T_0 = 240$ MeV and a initial radius of $R_0 = 5$ fm):
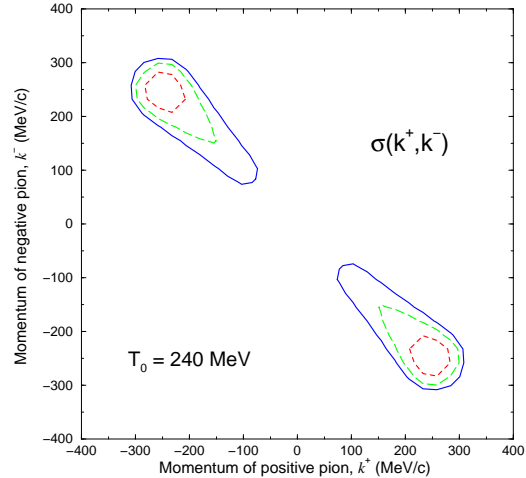
We therefore suggest that the data now being taken at RHIC be analyzed for indications of the described signature in the large-angle correlation. If indeed identified, this signal may offer a means for probing the degree of chiral restoration achieved and the subsequent relaxation.

[1] T.C. Petersen and J. Randrup, PRC61 (2000) 024906
[2] J. Randrup, Phys. Rev. C62 (2000) 064905